

NORTH CAROLINA  
DEPARTMENT OF WATER AND AIR RESOURCES

DIVISION OF GROUND WATER

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REPORT OF INVESTIGATIONS NO. 7

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GROUND-WATER SUPPLY  
OF  
CAPE HATTERAS NATIONAL SEASHORE  
RECREATIONAL AREA,  
NORTH CAROLINA

PART 6

---

By  
ORVILLE B. LLOYD, JR. AND ROBERTA B. DEAN

---



RALEIGH, NORTH CAROLINA

1968

NATIONAL PARK SERVICE  
WATER RESOURCES DIVISION  
FORT COLVILLE ROAD  
RESOURCES MANAGEMENT



NORTH CAROLINA  
DEPARTMENT OF WATER AND AIR RESOURCES  
GEORGE E. PICKETT, DIRECTOR

DIVISION OF GROUND WATER  
HARRY M. PEEK, CHIEF

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By  
ORVILLE B. LLOYD, JR. AND ROBERTA B. DEAN  
U. S. Geological Survey

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Prepared by the  
UNITED STATES GEOLOGICAL SURVEY  
in cooperation with the  
NATIONAL PARK SERVICE



RALEIGH, NORTH CAROLINA

1968

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June 24, 1968

The Honorable Dan K. Moore  
Governor of North Carolina  
Raleigh, North Carolina


Dear Governor Moore:

I am pleased to submit Report of Investigations No. 7, "Ground-Water Supply of Cape Hatteras National Seashore Recreational Area, North Carolina, Part 6," prepared by Orville B. Lloyd, Jr. and Roberta B. Dean, United States Geological Survey, in cooperation with the National Park Service.

This report presents the results of the sixth phase of intensive studies by the Geological Survey to evaluate and aid in the development of ground-water supplies in the National Seashore Recreational Area. The data in this report was collected at the Pea Island Campground.

Respectfully submitted,

George E. Pickett



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# GROUND-WATER SUPPLY OF CAPE HATTERAS NATIONAL SEASHORE RECREATIONAL AREA, NORTH CAROLINA

## Part 6

### Pea Island Campground

By

Orville B. Lloyd, Jr. and Roberta B. Dean

## INTRODUCTION

Pea Island Campground is part of Cape Hatteras National Seashore Recreational Area, and is located at the northern end of Hatteras Island, Dare County, North Carolina (fig. 1).

The purpose of the ground-water investigation at the campground site was to determine the thickness, extent, and lithic character of the water-bearing formations and the movement, quantity, and chemical quality of the ground water. The information obtained will be used in determining the feasibility of expanding the present facilities at Pea Island Campground.

The study was made at the request of the National Park Service as a part of the cooperative program between National Park Service and the U. S. Geological Survey to evaluate the ground-water supply of the recreational area. The report was prepared under the general supervision of E. B. Rice, District Chief, and the immediate supervision of G. G. Wyrick, Geologist U. S. Geological Survey.

The field work for this report was done during the period from November 29, 1965 to January 21, 1966. Methods of investigation consisted of test drilling with a power auger, collecting lithic samples at 5-foot intervals, gamma-ray logging the holes, and collecting water samples in the most permeable water-bearing zones in each test hole. Preliminary yield and water-level measurements were made in each of the tested zones, and a pumping test was conducted in the most productive water-bearing formation.

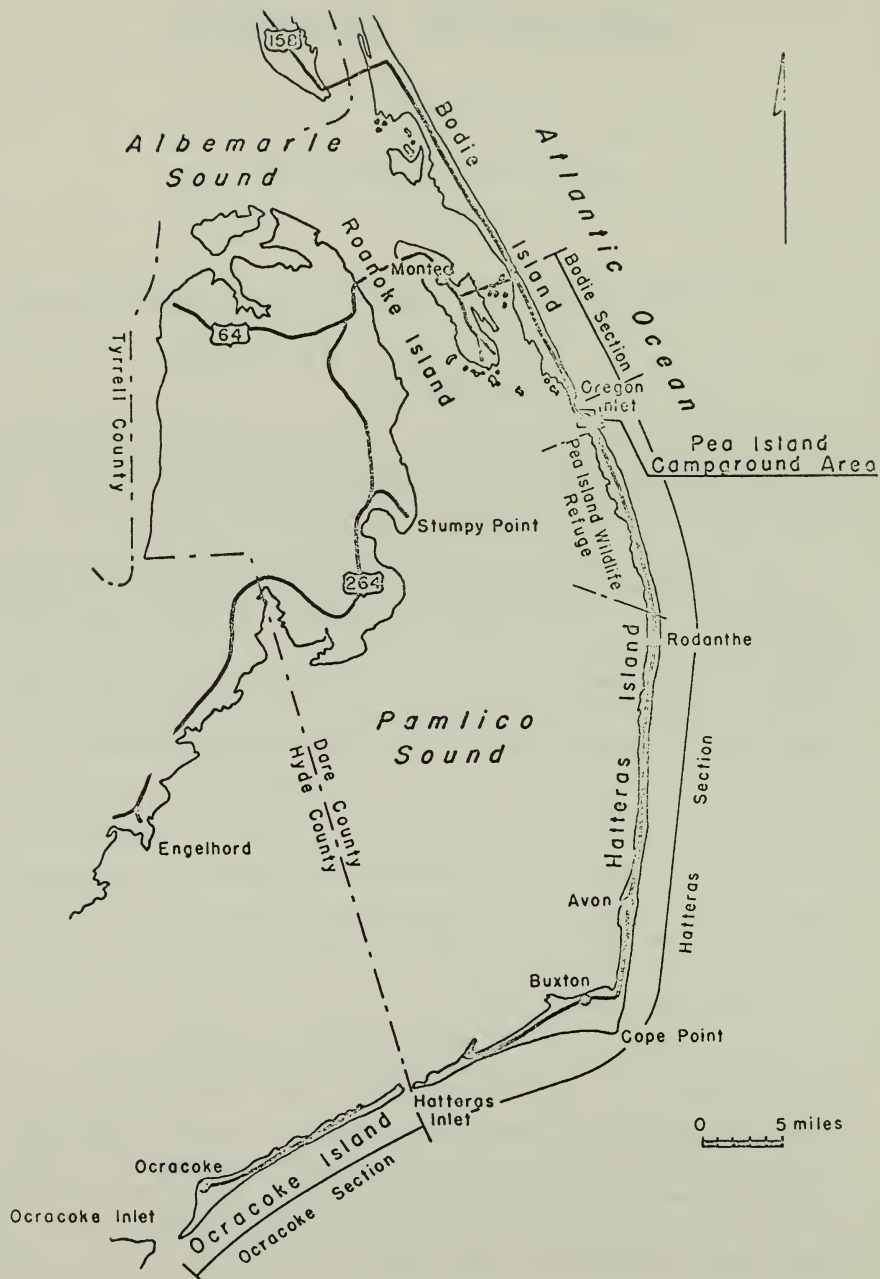


Figure 1-. Cape Hatteras National Seashore Recreational Area showing the location of Pea Island Campground Area.

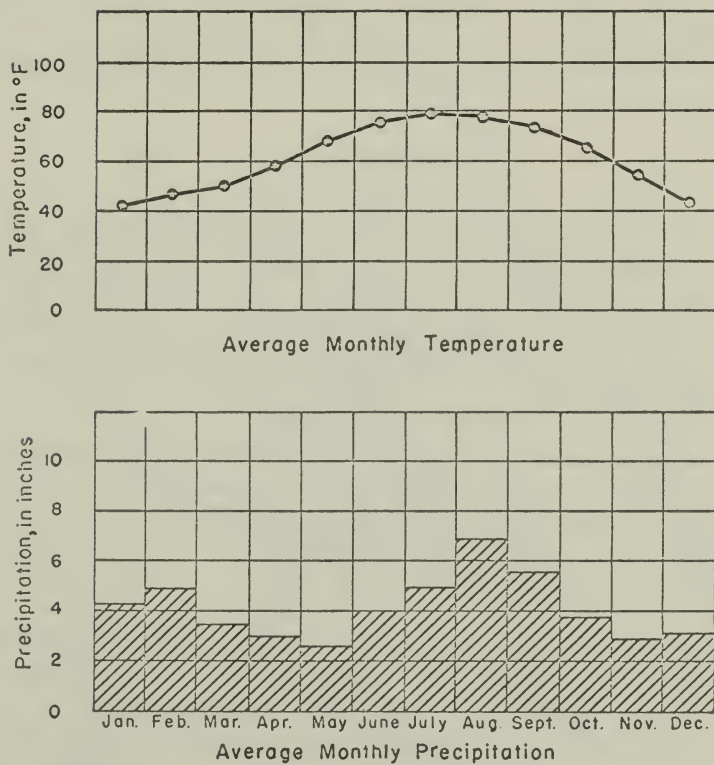


Figure 2-. Graphs showing climatic summary for Bodie Island, Dare County, North Carolina, for an 11 year period (1955-65).

A previous ground-water investigation in the Pea Island Campground area is described in the report entitled, "Ground-Water Supply of Cape Hatteras National Seashore Recreational Area, Part 2", by J. O. Kimrey.

The authors wish to acknowledge the assistance of Mr. Karl Gilbert, Superintendent, Cape Hatteras National Seashore Recreational Area, and the personnel of his staff, particularly Mr. Dennis McGinnis, Mr. Roy King, and Mr. Samuel Burrus for providing maps, power equipment, and pertinent information during the investigation.

## GEOGRAPHY

Pea Island Campground is located at the northern end of Hatteras Island, one of the long, narrow islands that comprise the "outer banks" of North Carolina. The campground site is bounded on the east by the Atlantic Ocean, the north by Oregon Inlet, the west by Pamlico Sound, and on the south by Pea Island Wildlife Refuge.

The area is covered with sand dunes that are moderately well stabilized by vegetation. The dunes range from about 6 to 25 feet above msl (mean sea level). Low, flat areas, about 5 feet above msl, occur between the dunes. A lake and marsh occupy the southwestern part of the area.

Average annual precipitation in the area is approximately 49.5 inches; the greater part occurs between June and October and in January and February (fig. 2). Average annual temperature in the area is about 61.5° F (Fahrenheit). The warmest months, May through October, coincide with the time of greatest rainfall (fig. 2). During these warm months, at least 12 percent of the potential ground-water recharge is lost through evapotranspiration.

The record of temperature and precipitation is based on eleven years of data compiled at the Bodie Island Climatological Station, 6 miles north of the Pea Island Campground area.

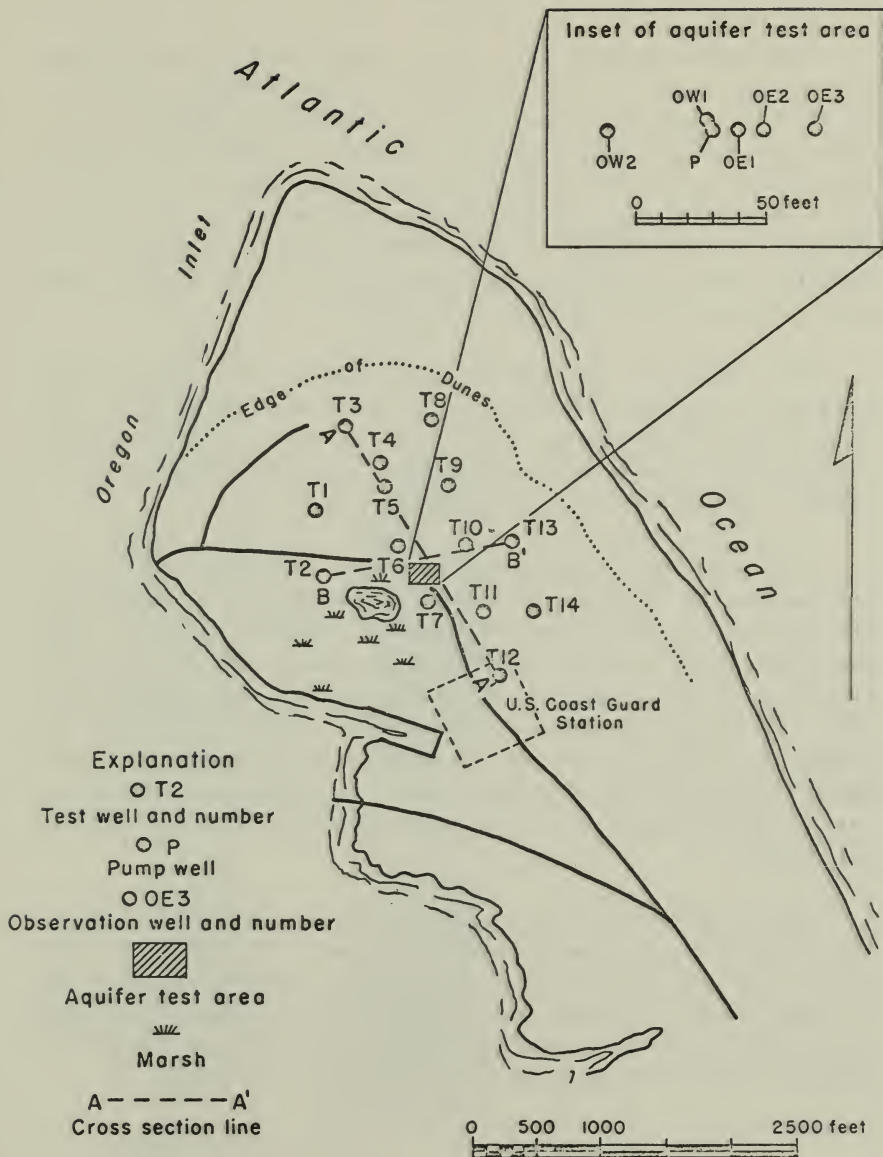


Figure 3-. Northern end of Hatteras Island showing location of test wells, cross-section lines, and aquifer test area.

## GEOLOGY

Sediments of post-Miocene age underlie Pea Island Camp-ground to a depth of about 60 feet. These sediments were deposited in a marine or near-marine environment where, generally, the coarser material was laid down in shallower, higher energy water than the finer material. After deposition, uplift and wave action exposed the youngest sediments in the form of offshore barrier beaches. The exposed sediments were sorted by the wind, which moved the finer sand particles to form the sand dunes that now cover the area.

The nature of the sedimentary material that underlies the sand dunes was determined by drilling 14 test holes (fig. 3), collecting and analyzing lithic samples taken at 5-foot depth intervals, and gamma-ray logging 12 of the test holes to aid in correlating the subsurface sedimentary material.

The gamma-ray log shows the relative concentration of natural gamma-ray emitting elements in rock material. Generally the concentration of these radioactive elements is low in sand and shell, high in silt, and highest in clay. Thus, in the Pea Island area, the gamma-ray log can be used to identify and correlate different sedimentary material. The intensity of the gamma-ray radiation was measured in milliroentgens per hour (MR/H) per log-scale division. Figure 4 illustrates the correlation between gamma-ray logs and the subsurface sedimentary materials.

The correlation of the gamma-ray logs and sedimentary material from the test wells indicates that five separate lithic units occur in the area from land surface to about 60 feet below land surface. These units are essentially flat lying, with generally little change in their physical character laterally (fig. 4). They may be generally described as follows:

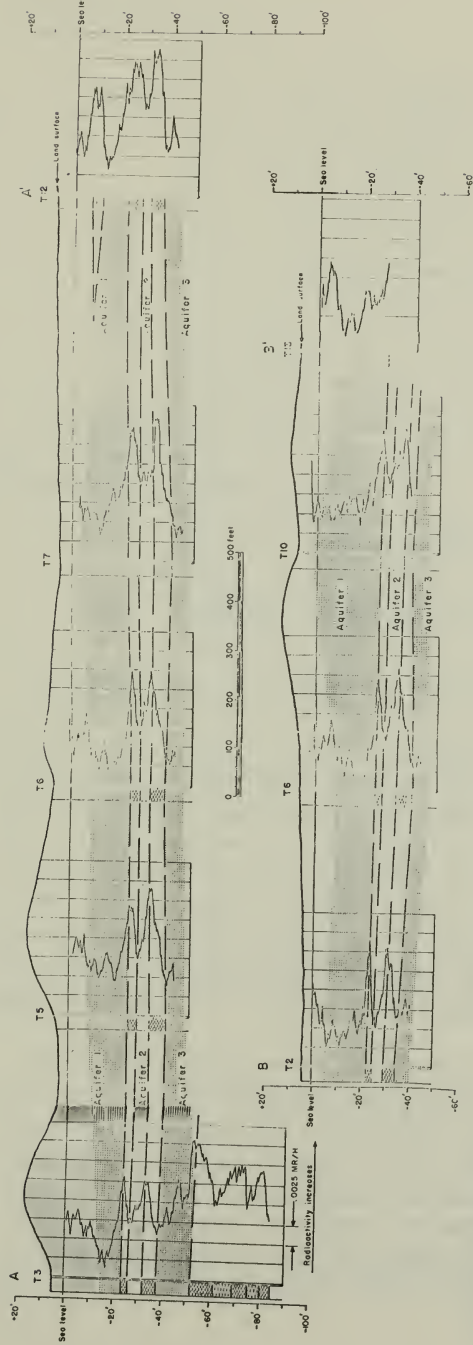


Figure 4. Geologic sections A-A' and B-B' showing lithologic units and potentiometric surfaces. Note see figure 3 for description of potentiometric surfaces and for data used in this figure.



Average Depth in feet (below land surface)		Average Thickness in feet
0-29	Sand, tan to gray. Fine to very fine grained, subrounded to subangular clear quartz sand in the upper 14 feet; and medium- to fine-grained subrounded clear quartz sand in lower 15 feet. Coarse quartz sand, iron stained quartz sand, ilmenite, garnet and muscovite (in lower part) prominent. Trace of fine-grained phosphate, lignitized wood, glauconite, smoky quartz and shell fragments.	29
29-33	Sand and silt, gray. Sixty percent very fine-grained subrounded quartz sand, 40% silt. Smoky quartz, ilmenite, garnet, and muscovite flakes prominent. Trace of glauconite, fine-grained phosphate and shell fragments.	4
33-39	Sand and silt, gray. Ninety percent fine- to very fine-grained subrounded quartz sand, 10% silt. Smoky quartz, ilmenite, garnet, muscovite flakes, shell fragments, and glauconite prominent. Trace of lignitized wood, fine-grained phosphate, and pyrite.	6
39-44	Sand and silt, gray. Sixty percent very fine-grained subrounded quartz sand, 40% silt. Garnet, ilmenite, muscovite flakes, shell fragments, and glauconite prominent. Trace of fine-grained phosphate, coarse-grained quartz sand and fine gravel.	5



Average  
Depth in feet  
(below land surface)

Average  
Thickness  
in feet

44-60 +  
—

Sand, greenish-brown.  
Coarse- to very fine-grained  
subrounded to subangular  
clear quartz sand. Muscovite  
flakes, shell fragments,  
fine gravel and ilmenite  
prominent. Trace of garnet  
and fine-grained phosphate.

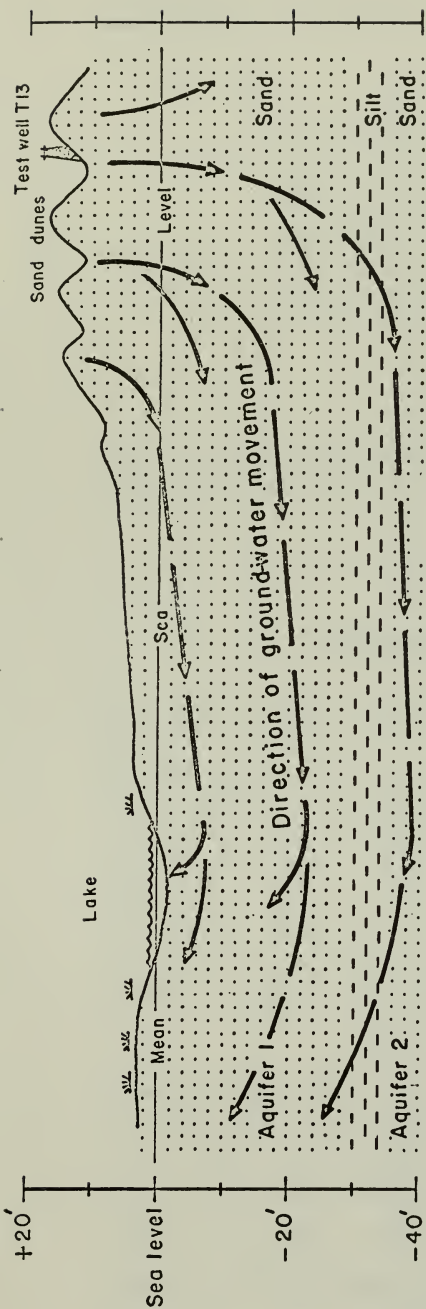
The sediments between land surface and about 30 feet below land surface, constitute the aquifer that contains the potable ground water in the area.

## GROUND WATER

### Source, Occurrence and Movement

Ground water is that part of precipitation that seeps into the ground and percolates to the zone of saturation, the zone in which all pore spaces are filled with water. Rainfall on the proposed well-field area at Pea Island is estimated at about 225 acre-feet per year, or about 200,000 gpd (gallons per day). Correlation of ground-water level, temperature, and rainfall records at Bodie Island indicate at least 25 percent of the average daily rainfall in the area percolates to the zone of saturation. Thus, about 50,000 gpd are available for withdrawal from the ground-water reservoir without exceeding the estimated present rate of daily recharge.

Ground water is stored between the particles of sedimentary material that underlie the area, and occurs under both artesian and non-artesian conditions. Ground water under artesian conditions completely fills a permeable zone and is confined above and below by impermeable beds so that its surface is not free to rise and fall in response to changes in pressure. Ground water under non-artesian conditions only partially fills a permeable zone and its surface is free to rise and



Zone of Discharge —>

<— Zone of Recharge

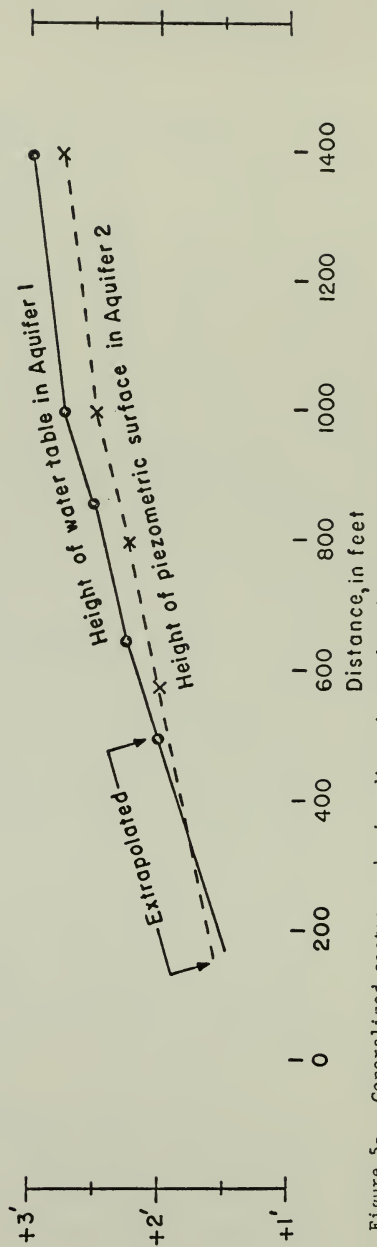


Figure 5-. Generalized section, showing direction and paths of ground-water movement, zones of discharge and recharge and the height of water-table and piezometric surfaces (December 15, 1965) in Aquifers 1 and 2, respectively.

fall. The water at the campground, from land surface to 30 feet below land surface, is under non-artesian or water-table conditions. The water that occurs in the permeable zones below 30 feet is under artesian conditions.

Ground water moves through sedimentary material in response to gravity, moving from areas where water-level elevations are relatively high toward areas where they are relatively low. The highest water levels at Pea Island were recorded in the dune mass (table 1; T1, T5, T8, T10, T12, T13 and T14), and the lowest water levels were recorded at the southwestern edge of the dunes near the lake and marsh (table 1; T2, T6, T7, and T11). Most of the ground water moves laterally from the dunes (the area of recharge) toward the lake and marsh (the area of discharge) (fig. 5). However, some of the lateral movement is away from the campground site, toward Oregon Inlet and the Atlantic Ocean.

In the dunes the water level in the shallow sands is about 0.25 feet higher than that in the deeper sands. This hydraulic head difference causes movement of water downward through the water-bearing zones. This downward-movement pattern extends to the area just east and north of the lake and marsh, where the differences in water level between the shallow and deep sands are negligible. Extrapolation of the water levels indicate a reversal in the flow pattern in the southwest portion of the area. Here the ground water moves upward from the deeper to shallower sands, discharging in the immediate vicinity of the lake, marsh, and Pamlico Sound (fig. 5).

### Aquifers

An aquifer is a formation, part of a formation, or group of formations that contains usable amounts of water. Generally the coarser grained materials constitute the most permeable zones and, consequently, the most productive aquifers. Finer grained materials that separate aquifers from one another retard the flow of ground water between aquifers and are referred to as aquicludes.

Three aquifers separated by two thin aquicludes were defined between land surface and about 60 feet below land surface in the campground area (fig. 4). The aquifers are numbered 1 through 3 from land surface downward, respectively.

TABLE 1. CHLORIDE, YIELD, AND WATER-LEVEL CHARACTERISTICS OF  
AQUIFERS 1, 2, AND 3 AT PEA ISLAND CAMPGROUND DURING  
TEST DRILLING.

Date	Well*	Chloride in ppm			Yield in gpm			Water level above Mean sea level, in feet		
		Aquifer			Aquifer			Aquifer		
		1	2	3	1	2	3	1	2	3
12/13/65	T1	190	330	-	8	3	-	2.66	2.68	-
12/14/65	T2	40	480	-	20	3	-	2.38	2.18	-
11/30/65	T3	125	865	4320	-	-	-	-	-	-
12/1/65	T4	-	-	-	-	-	-	-	-	-
12/3/65	T5	150	1470	670	12	1	15	2.92	2.27	1.77
12/6/65	T6	30	795	4500	25	3	12	2.41	2.31	0.59
12/6/65	T7	10	1440	18400	25	4	15	2.05	1.84	0.91
12/10/65	T8	1100	2210	-	8	3	-	2.90	2.70	-
12/9/65	T9	410	1490	-	10	1	-	2.68	-	-
12/8/65	T10	80	2270	9410	12	4	3	2.96	2.66	1.96
12/8/65	T11	50	960	14200	22	1	15	2.21	-	-
12/7/65	T12	530	4560	24600	15	1	5	2.75	-	1.04
12/10/65	T13	80	2620	-	20	8	-	3.03	2.73	-
12/13/65	T14	1840	2090	-	20	4	-	3.42	2.52	-

\*See figure 3 for location of wells.

Aquifer 1, between land surface and about 29 feet below land surface, will supply a limited amount of potable water in the Pea Island Campground area. High concentrations of chloride in water from Aquifer 2 coupled with low yield, and excessively high concentrations of chloride in water from Aquifer 3, precludes the use of the deeper aquifers for water supply in the area (table 1).

### Aquifer Test

A pumping test was conducted at Pea Island on January 18, 19, and 20, 1966, to determine the amount of water that can be pumped from Aquifer 1, and to detect any change in the chemical quality of the water during pumping.

A 2-inch diameter well screened from 15 to 25 feet below land surface was installed between the sites of test wells T6 and T7. Five observation wells were installed at various distances from the pump well so that water-level observations could be made (fig. 3). Observation well OW1 was screened in Aquifer 2 from 34 to 37 feet below land surface, and the other observation wells were screened in Aquifer 1 from 18 to 21 feet below land surface.

Water levels were observed in the wells and the lake for 15 hours before the test began. The pretest water-level fluctuations in Aquifer 1 were insignificant, and correction of the aquifer test data for tidal effects was unnecessary.

The production well P was pumped 54 hours. For the first 24 hours the pumping rate was 15 gpm and for the remainder of the test it was 28 gpm. At the end of the test the water-level recovery was measured for 2 hours. Figure 6 illustrates the water levels prior to, during, and after the test in the observation wells. The drawdown and recovery data for observation well OE3 are omitted from the hydrograph because the differences in drawdown and recovery in observation wells OE3 and OW2 were never greater than 0.03 foot.

Analysis of the test data indicates that Aquifer 1 has a coefficient of transmissibility of 9200 gallons per day per foot, and a coefficient of storage of  $4.1 \times 10^{-2}$ . These hydraulic characteristics were defined by applying the non-equilibrium formula (Theis, 1935) to the test data.



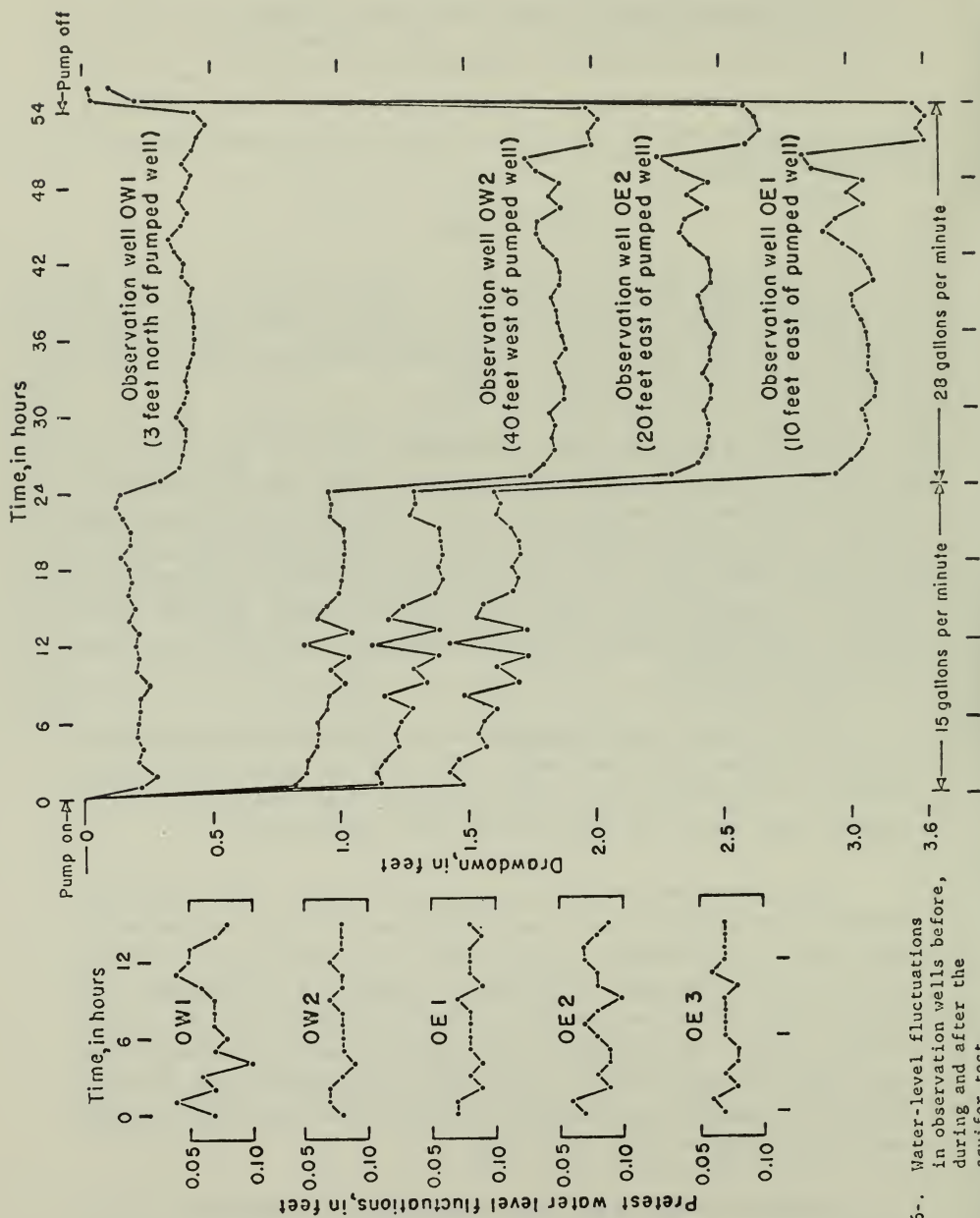


Figure 6-- Water-level fluctuations in observation wells before, during and after the aquifer test.

Upward leakage of ground water from Aquifer 2 to Aquifer 1 caused the data collected after the first hour of pumping to deviate from the type curve derived from the non-equilibrium formula. The result was that observed drawdown at the observation wells screened in Aquifer 1 was less than that which would have been predicted by using the coefficients established above. In addition, water-level declines were recorded in observation well OW1, which was screened in Aquifer 2 (fig. 6). The leakage occurred after a 0.5 foot head differential was developed between the aquifers. The amount of leakage increased with the spread of the cone of depression, and at the end of one day of pumping approximately 25 percent of the 15 gpm was coming from Aquifer 2.

The changes in the chemical quality of the water before and during the aquifer test, and the influence of these changes on the potential ground-water production in the area are discussed in the Quality of Water section.

## QUALITY OF WATER

The suitability of ground water for use in public water supplies is determined by the quality of the water. In general, the most significant factors of water quality in the area of study, are the concentrations of chloride, iron and hardness-causing constituents, and the presence of hydrogen sulfide and organic color. These may impart taste, odor, or other undesirable characteristics to the water. Complete chemical analyses of water samples taken from Aquifers 1 and 2 during the test are shown in table 2. Aquifer 2 was sampled because it contributed about 25 percent of the total ground-water production during pumping.

### Chloride

The chloride content of water samples collected during the test drilling ranged from 10 to 24,600 ppm (table 1). The concentration of chloride in water from Aquifer 1 was less than the 250 ppm maximum recommended by the U. S. Public Health Service, except in test wells T8, T9, T12, and T14 (table 1). Chloride in water samples from Aquifer 2 and 3 exceeded 300 ppm without exception (table 1).

TABLE 2. CHEMICAL ANALYSES OF GROUND WATER FROM PUMPED WELL P  
AND OBSERVATION WELL OW1 AT PEA ISLAND CAMPGROUND.

(parts per million except specific conductance and pH and color)

Well	P	P	OW1	OW1
Aquifer	1	1	2	2
Date of collection	1-18-66	1-20-66	1-19-66	1-20-66
Time of collection	Beginning of test	After 54 hours pumping	After 26 hours pumping	After 54 hours pumping
Silica (SiO <sub>2</sub> )	16	19	25	24
Iron (Fe)	.16*	.05*	.02**	.02**
Manganese (Mn)	.00*	.00*	.00**	.00**
Calcium (Ca)	34	38	8.0	8.5
Magnesium (Mg)	5.3	6.6	4.2	3.4
Sodium (Na)	23	31	110	108
Potassium (K)	1.3	2.2	15	15
Bicarbonate (HCO <sub>3</sub> )	123	131	193	193
Sulfate (SO <sub>4</sub> )	1.8	3.6	4.0	3.2
Chloride (Cl)	40	55	92	90
Fluoride (F)	.2	.3	.9	.9
Nitrate (NO <sub>3</sub> )	.2	.3	.3	.3
Phosphate (PO <sub>4</sub> )	.6	.6	1.0	1.0
Dissolved Solids (Sum ppm)	182	221	355	349
Residue on evaporation	180	232	348	339
Hardness as CaCO <sub>3</sub>	108	121	37	35
Noncarbonate hardness	7	14	0	0
Specific conductance (micromhos)	319	384	592	589
pH	7.8	8.0	8.1	8.1
Color	25	35	20	20

\*total

\*\*dissolved



The chloride content in water from Aquifer 2 decreased about 900 ppm during the period between the test drilling in December, 1965, and the aquifer test in January, 1966 (table 1 and 2). The high concentrations of chloride in December, can be attributed to two months of drought between October 9, and December 7, 1965. During this period the fresh-water head in Aquifer 1 was depleted by natural discharge and brackish water encroached into Aquifer 2. Three inches of rain between December 6, 1965, and January 18, 1966, recharged the ground-water reservoir and reestablished a fresh-water head that was sufficient to flush the brackish water from Aquifer 2 in the aquifer test area.

During the aquifer test, the chloride content in water from the pumped well increased from 37 to 55 ppm. It fluctuated between 37 and 43 ppm for the first 20 hours, and increased arithmetically with the log of time for the remainder of the test (fig. 7). The increase was due to induced upward leakage of the more brackish water from Aquifer 2.

The chloride content in water from observation well OW1 decreased from 104 to 85 ppm during the aquifer test. It decreased arithmetically with the log of time for the first 45 hours, and increased slightly during the remainder of the test (fig. 7). To account for the decrease in chloride, it is assumed that fresher water was diverted laterally, during pumping, to observation well OW1 from a nearby and more permeable zone in Aquifer 2.

The trends in chloride during the aquifer test indicate that water pumped from Aquifer 1 could be rapidly contaminated by upward leakage of saline water from Aquifer 2. Such contamination would have occurred at the end of one day if the water in Aquifer 2 had contained 1000 ppm of chloride during the aquifer test. In addition, ground water in the area is subject to overland salt-water contamination from storm tides.

Chloride, then, is the most critical chemical constituent in the ground water at Pea Island Campground, and is a factor that must be considered in developing a water supply in the area.

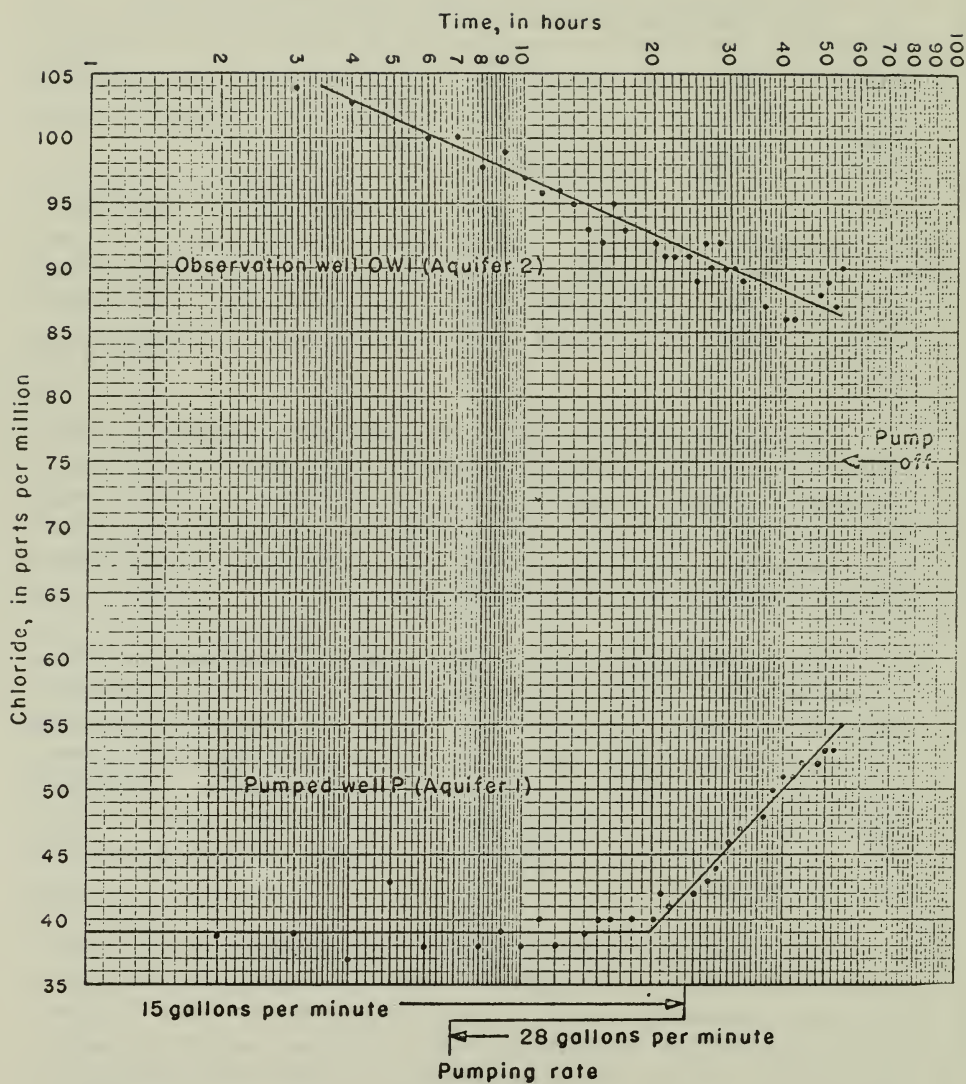


Figure 7-. Change in chloride concentration during the aquifer test in water from pumped well P, and observation well OW1.

## Iron

The presence of iron in ground water is the result of its solution from iron-bearing minerals in the zone of saturation. The solution of iron is associated with low pH of water resulting from decomposing organic material and certain types of anaerobic bacteria which promote a reducing environment.

Water containing large amounts of iron is objectionable because it stains clothes and porcelain fixtures, clogs well screens, and has a disagreeable taste. Such waters can be treated economically by aeration and filtration (Nordell, 1961). Iron is not objectionable in concentrations less than 0.3 ppm in water used for most domestic purposes.

The iron content in water from the pumped well decreased from 0.16 to 0.05 ppm during the aquifer test. It remained at 0.02 ppm in water from observation well OW1 during the test. The decrease at the pumped well was probably due to upward leakage of water containing lower concentrations of iron<sup>3</sup> from Aquifer 2. Treatment for the removal of iron is not necessary to make the water satisfactory for domestic use.

## Hydrogen sulfide

Hydrogen sulfide is a gas produced by the anaerobic decomposition of organic matter or the solution of sulfide minerals. Water having a hydrogen sulfide content in excess of 0.5 ppm has a strong, disagreeable odor characteristic of rotten eggs. Hydrogen sulfide may be economically removed from water by aeration and/or chlorination (Nordell, 1961).

During the aquifer test, the hydrogen sulfide content in water from the pumped well increased from 0.5 to 1.0 ppm. Treatment, by aeration, is recommended for its removal.

## Hardness

Hardness is an indication of the soap-consuming ability of a water and can be recognized by the curd that is formed with soap. Hardness of water is due to the presence of alkaline-earth minerals in solution, particularly calcium and magnesium. These elements are derived from shells in sedimentary materials. All hardness-causing constituents dissolved in a water

are reported together as an equivalent amount of calcium carbonate ( $\text{CaCO}_3$ ). The following scale is used by the U. S. Geological Survey to classify the hardness of water.

Hardness as $\text{CaCO}_3$	Classification
0-60 ppm	Soft
61-120 ppm	Moderately Hard
121-180 ppm	Hard
180+ ppm	Very Hard

The hardness of water from the pumped well increased from 99 to 116 ppm, and the hardness of water from observation well OW1 decreased from 50 to 33 ppm during the aquifer test (fig. 8). These waters are classified as moderately hard and soft respectively. Treatment for lowering hardness is not considered necessary if the water is to be used only as a drinking water supply.

### Organic color

The presence of organic matter in shallow aquifers may impart a brown color to the water. Organic color in excess of 15 units is considered objectional for esthetic reasons by the U. S. Public Health Service.

Organic color increased from 25 to 35 units in water samples taken from the pumped well during the aquifer test (table 2). Even though the color ranged from 10 to 20 units above the recommended standard, the removal of organic color is difficult and is not economically feasible in small water-supply installations.

### Quality of Water Changes Caused by Ion-Exchange and Mixing

The mixing, at a given volumetric ratio, of two waters containing known amounts of chemical constituents will result in a composite water sample containing predictable amounts of chemical constituents provided: (1) that no additional ions are added to the water by the solution of host-rock minerals, (2) that no constituents are precipitated by the mixing of the waters, and (3) that ion-exchange does not take place between the water and the host-rock minerals. Data from the test indicates that water from Aquifer 2 mixed with water from Aquifer 1 during pumping. Both the ratio of mixing and the amount of

20



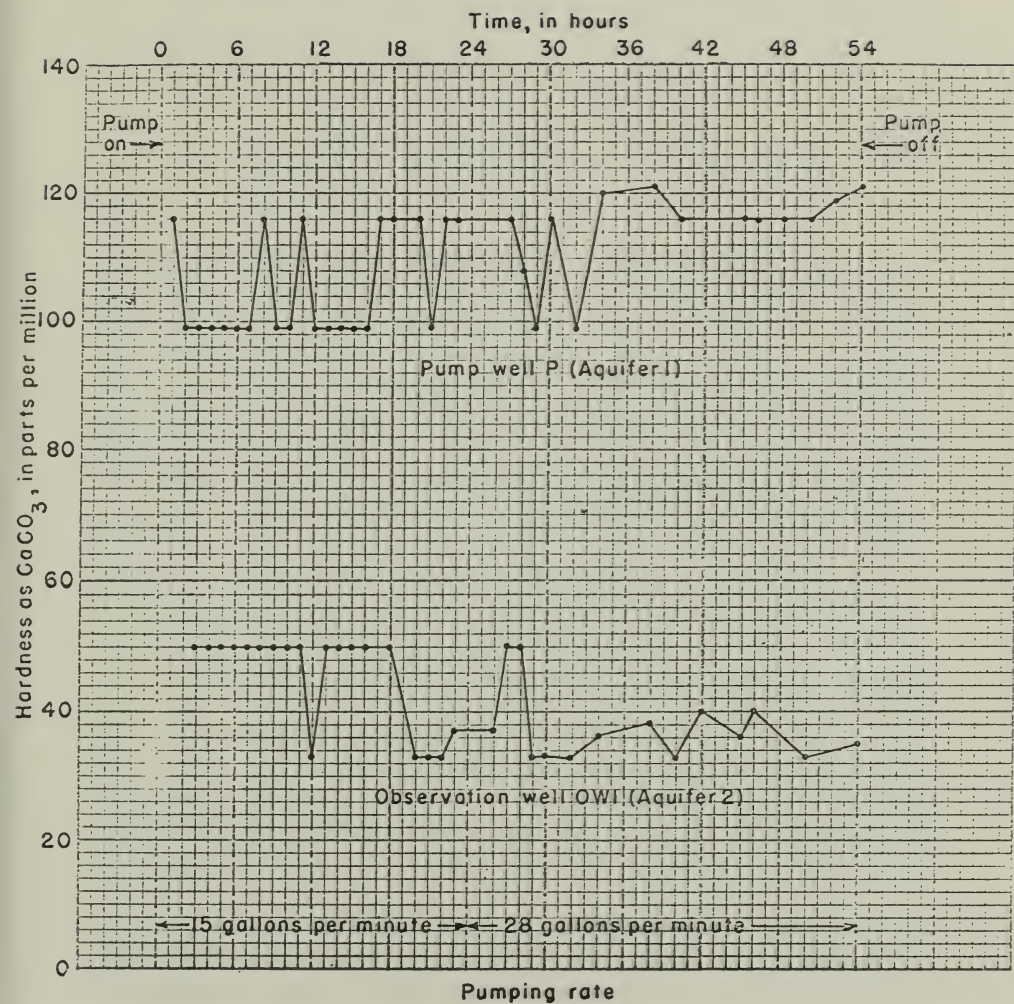


Figure 8-. Change in hardness as  $\text{CaCO}_3$  during the aquifer test in water from pumped well P, and observation well OW1.

chemical constituents in water from Aquifers 1 and 2 were known, but the concentration of certain constituents in the composite water sample did not agree with the predicted amounts. As the discrepancies were in the predicted amounts of calcium, magnesium and sodium, ions commonly affected by ion-exchange processes, it was determined that both simple mixing and ion-exchange processes affected the resulting quality of water,

A number of common minerals, especially clay minerals and glauconite, exhibit a capacity for ion-exchange when exposed to ground water. The type of ion-exchange that takes place depends upon the type of exchange material, and the chemical composition of the water in contact with the exchange material.

Lithic samples taken during test drilling contained prominent amounts of glauconite in Aquifer 2 and trace amounts in Aquifer 1. Ground water in contact with glauconite frequently undergoes a natural softening process in which the calcium and magnesium ions in solution are exchanged for sodium ions that are held by the glauconite. At Pea Island the solution of shell fragments by ground water is the principal source of calcium and magnesium ions, and the mixing of ocean water with ground water is the principal source of sodium ions.

A comparison of the chemical composition of water samples from Aquifers 1 and 2 (table 2), collected at the beginning of the test, suggests that a cation-exchange process takes place during recharge. The result is a natural softening of the water as it moves downward from Aquifer 1 to Aquifer 2. This softening by cation-exchange is indicated by the marked decrease in the proportions of calcium and magnesium, and an increase in the proportion of sodium greater than can be accounted for by the mixing of ground water with dilute ocean water (table 2).

Changes in the chemical composition of the water in Aquifer 1, from the beginning to the end of the test (table 2), suggest that the reversal in flow directions due to pumping resulted in a reversal of the ion-exchange reaction that occurred during recharge. The calcium and magnesium ions adsorbed by the glauconite during recharge were released and exchanged for sodium ions during pumping. Favorable conditions for this type of reaction exist when there is a change in the composition of the water surrounding an ion-exchange mineral, such as an increase in the percentage of sodium ions. This increase in

TABLE 3. ACTUAL VALUES OF MAJOR CONSTITUENTS IN WATER FROM THE PUMPED WELL AT THE END OF THE AQUIFER TEST, AND CALCULATED VALUES ASSUMING 25% OF THE WATER WAS COMING FROM AQUIFER 2 AFTER 24 HOURS OF PUMPING.

	Actual ppm	Calculated ppm	Actual epm	Calculated epm
Silica	19	18		-
Calcium	38	28	1.90	1.40
Magnesium	6.6	5.0	.54	.41
Sodium	31	45	1.35	1.96
Potassium	2.2	4.8	.06	.12
Bicarbonate	131	140	2.15	2.29
Sulfate	3.6	2.4	.07	.05
Chloride	55	53	1.55	1.50
Sum of ppm	221	224	-	-

sodium ions occurred as the more saline water from Aquifer 2 moved upward to Aquifer 1 as a result of pumping.

Approximately 25 percent of the pumped water was coming from Aquifer 2 at the end of the test. Thus, the changes in the chemical composition of the water from Aquifer 1, during the test, were not the result of ion-exchange alone, but a combination of both simple mixing and ion-exchange (table 3). The influence of ion-exchange is seen in the increase in calcium and magnesium. A simple mixture would have resulted in a decrease in these constituents. Also, a mixture containing 25 percent water from Aquifer 2 and 75 percent from Aquifer 1 would have resulted in a greater increase in sodium than was observed. The changes noted in the major constituents not affected by the ion-exchange process, such as bicarbonate,

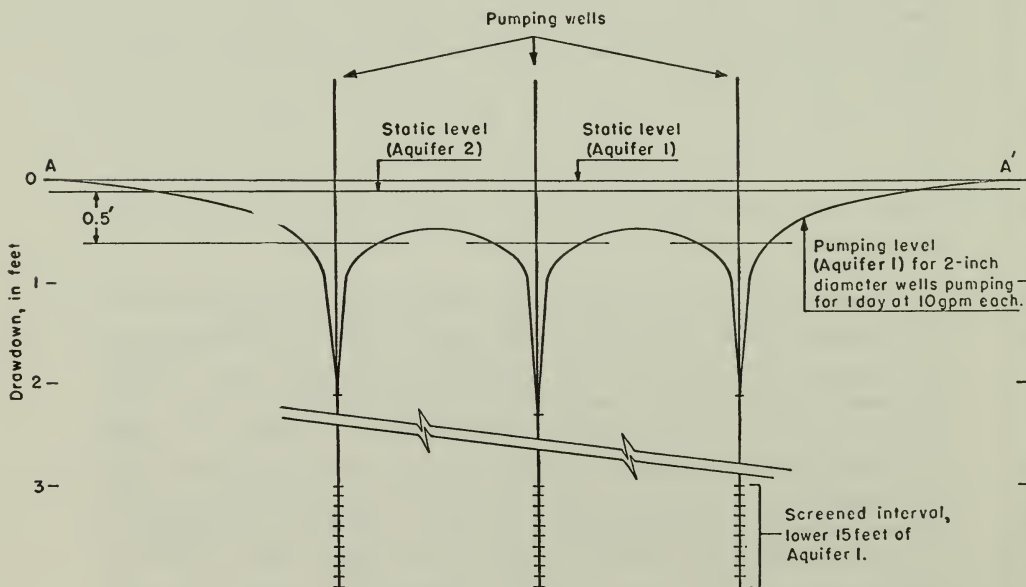
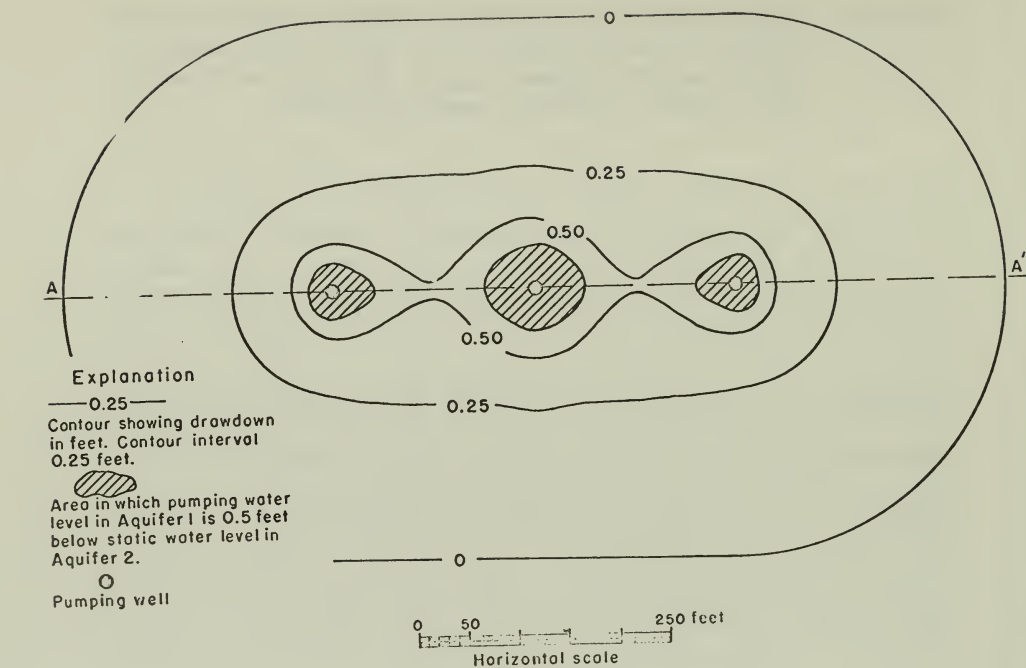


Figure 9-. Map and section showing the theoretical drawdown in Aquifer 1 for three, 2-inch diameter wells pumping for one day at 10 gpm each.



chloride, and silica, can be accounted for entirely by simple mixing of the two water types in the ratio of 25 percent from Aquifer 2 and 75 percent from Aquifer 1 (table 3).

## WELL-FIELD DESIGN AND MANAGEMENT

A ground-water supply system in the Pea Island Campground area will be constantly threatened by salt-water encroachment. Therefore, proper well-field design and careful management will be necessary to insure a satisfactory and safe development of the water supply. A well field in the area should be designed to minimize the danger of overland salt-water contamination from storm tides, and lateral and vertical salt-water encroachment within the aquifers.

### Well and Well-Field Design

The quality of water and aquifer test data compiled during this investigation indicate: (1) the upward leakage of ground water from Aquifer 2 to Aquifer 1 should not exceed 25 percent of the total production and (2) the area of influence of the cone of depression in Aquifer 1 should not extend more than 300 feet from the wells after pumping for one day. These limitations can be approached through any one of a variety of well types, well diameters, well spacings and pumpage rates. However, pumpage rates should be controlled so that critical water-level differences between Aquifers 1 and 2 are not exceeded. That is, the area in which the pumping level in Aquifer 1 is 0.5 feet below the static level in Aquifer 2 (as shown in fig. 9) should be as small as practically possible during pumping. The following specifications are suggested for the hydraulic characteristics of Aquifer 1 and the upward leakage limitations. However, they constitute only one of the possible means of preventing encroachment.

Analysis of the data indicates that 2-inch diameter wells, screened throughout the lower 15 feet of Aquifer 1 with #10 to #15 (40 to 60 mesh) slot screen, should be spaced at least 200 feet apart and pumped no more than 10 gpm each. The length of screen should be adjusted to any thinning and thickening of the medium-grained sand in the lower portion of Aquifer 1. Figure 9 illustrates the theoretical drawdown effects of such a system after continuous pumping for one day.

Scavenger wells incorporated in the well-field design proposed above might be used to reduce the amount of upward leakage and allow longer periods of extended pumping for any given concentration of chloride occurring in water from Aquifer 2. A scavenger well is screened between the supply well and the source of salt water. When pumped simultaneously with the supply well, the scavenger well will intercept the encroaching saline water and allow the supply well to yield fresh water (Long, 1965).

The principle, applied to the Pea Island area, will reduce head differences between the aquifers during pumping. Equal water levels in the aquifers during pumping will prevent water moving vertically from one aquifer to another. This condition could be approached by placing wells that are screened in Aquifers 2 and 3 adjacent to wells that are screened in Aquifer 1, and pumping all wells simultaneously, through separate systems.

Additional information regarding the ability of Aquifers 2 and 3 to store and transmit water would be necessary to establish the proper pumping rates for the scavenger wells. Nevertheless, the method is worth considering because it may be another means of safely developing the fresh-water supply in the Cape Hatteras National Seashore Recreational Area.

If the limiting factors of upward leakage and extent of the cone of depression are adhered to, the possibility of lateral and vertical salt-water contamination from within the aquifers should be greatly reduced. Overland flooding from storm tides could be generally eliminated by completely encircling the recharge and well-field area with sand dunes.

### Well-Field Location

Using as a guide the distribution of chloride concentrations in water from Aquifers 1 and 2 during December, 1965 (table 1) the best location for a well field is near the center of the area outlined by test wells T1, T2, T6, and T7 (fig. 3). The wells should be installed along a straight line that parallels the east-west portion of the access road.

### Monitoring System

Regardless of the precautions taken to reduce the probability of salt-water encroachment, all the possible causes and

directions of encroachment should be observed. Continuous water-level records in Aquifers 1 and 2, should be collected in observation wells adjacent to and about 600 feet from the production wells. In addition, the chloride content in water from Aquifers 1 and 2, should be determined frequently, if not continuously by conductivity recorders, from the production wells and from observation wells placed on the perimeter of the well field. Such a monitoring system should allow early detection of any salt-water encroachment.

## CONCLUSIONS

1. Five units of sand and silt underlie the Pea Island Campground area to depths of about 60 feet below land surface. These sedimentary units occur as three sand aquifers separated by two thin silt aquicludes.

2. The medium-grained sand unit between approximately 9 and 24 feet below mean sea level is the most desirable water-bearing zone for developing future ground-water supplies, because it contains the largest amount of water of good quality in the area.

3. Upward leakage of ground water, from Aquifer 2 and Aquifer 1, occurs after more than a 0.5 foot head differential is established between these water-bearing zones.

4. The chloride content in water from the aquifers changes rapidly with small, natural fluctuations in the water table, and is subject to rapid change through inundation by sea water.

5. The chemical quality of water pumped from Aquifer 1 is significantly affected by upward leakage from Aquifer 2. The quality of the composite water is due to both simple mixing and ion-exchange processes. The concentrations of constituents such as bicarbonate, silica, and chloride result from simple mixing. However, the concentrations of constituents such as calcium, magnesium, and sodium are controlled by ion-exchange processes first, and then, after ion-exchange equilibrium is established, by simple mixing.

6. Water samples collected during the aquifer test indicate that water from wells screening Aquifer 1 will require treatment by aeration and chlorination to remove objectionable

concentrations of hydrogen sulfide. All other chemical constituents were below the maximum concentrations recommended for drinking water by the U. S. Public Health Service.

7. Aquifer 1 will be threatened constantly by salt-water contamination from inundation by sea water and/or induced encroachment from over pumping. Thus, certain restrictions should be considered in the well and well-field design as follows:

- a. The well field should be encircled with sand dunes, and located near the center of the area outlined by test wells T1, T2, T6, and T7 (fig. 3).
- b. Individual supply wells should be screened throughout the lower 15 feet of Aquifer 1 with #10 to #15 slot (40 to 60 mesh) screen. Length of screen should be adjusted to any thinning and thickening of the medium-grained sand in the lower portion of Aquifer 1.
- c. The individual supply wells should be pumped no more than 10 gpm each and spaced at least 200 feet apart in a straight line.

8. Scavenger wells, incorporated in the well-field design, are a possible means of reducing the amount of upward leakage and allowing longer periods of extended pumpage when the chloride content in water from Aquifer 2 is high.

9. Observations of water levels and chloride content should be made frequently if not continuously in Aquifers 1 and 2 to detect any salt-water encroachment that may occur. The observation wells should be placed adjacent to the production wells and on the perimeter of the well field.

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